2015 NEPP Tasks Update for Ceramic and Tantalum Capacitors

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List of Acronyms

AF	acceleration factor	IM	Infant mortality
BI	burning-in	JAXA	Japan Aerospace Exploration Agency
BME	base metal electrode	MLCC	multilayer ceramic capacitor
DCL	direct current leakage	PHS	polymer hermetically sealed
ESR	Equivalent series resistance	PME	precious metal electrode
FB	ferrite beads	PV	Prokopowicz-Vaskas
FR	failure rate	QA	quality assurance
HALT	highly accelerated life testing	RVT	random vibration testing
HSD	hot solder dip	S&Q	screening and qualification
HT	High temperature	VR	rated voltage
HTS	high temperature storage		

Reasons for NEPP Tasks on Capacitors

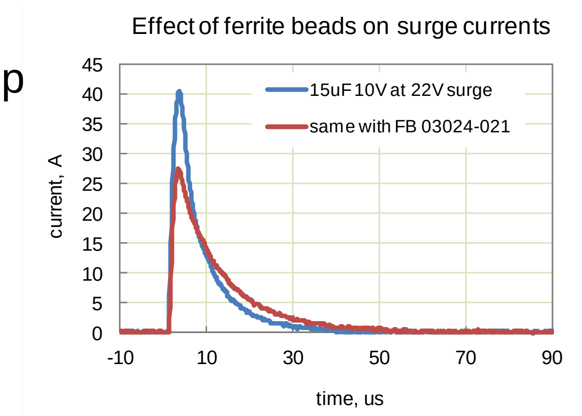
- Capacitors constitute the majority of elements in electronic systems.
- New technologies and designs appear with increasing speed. There is a need for optimization of S&Q procedures and setting adequate requirements.
- Physics behind degradation and failure processes needs better understanding.
- Capacitors exhibit both, infant mortality and wear-out failures, and can be used as models to refine quality assurance approaches for variety of space components.

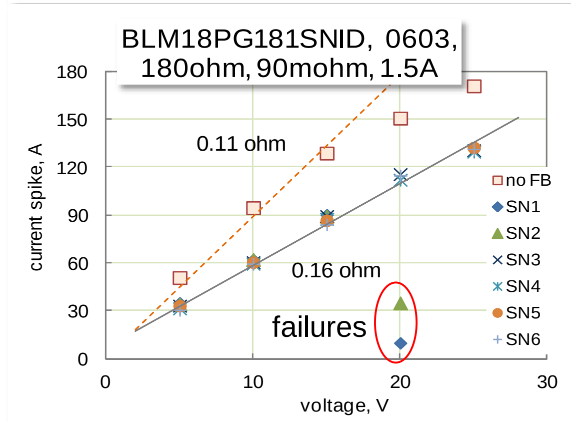
Outline

- Update on tantalum capacitors.
  - Use of ferrite beads as surge current limiters.
  - Polymer capacitors.
  - Random vibration testing of advanced wet capacitors.
  - Future work.
- Update on ceramic capacitors.
  - Effect of cracking on degradation of MLCCs at high temperatures.
  - Can we use automotive industry capacitors?
  - Future work.

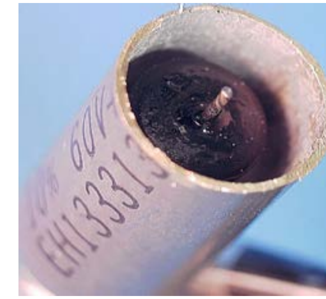
Ferrite Chip Beads as Surge Current Limiters

- Contrary to inductors, FBs at high frequencies work like resistors and dissipate power in the form of heat.
- NEPP report contains (https://nepp.nasa.gov/):
  - Analysis of requirements of DLA DWG#03024 for hi-rel chip
  - Results of testing of 12 types of FB;
  - Data on the specific features of FBs;
  - Evaluation of the robustness of FB to soldering stresses;
  - Behavior of FBs under multiple high current spikes.
  - Recommendations for reliability assurance of tantalum capacitors operating under surge current conditions.
- Conclusion:
  - Due to decrease of impedance with frequency and current, the effective resistance remains substantially below the value that is required to limit surge in tantalum capacitors (from 1 to 5 Ohm).
  - Recommendations on current derating are available at https://nepp.nasa.gov/.



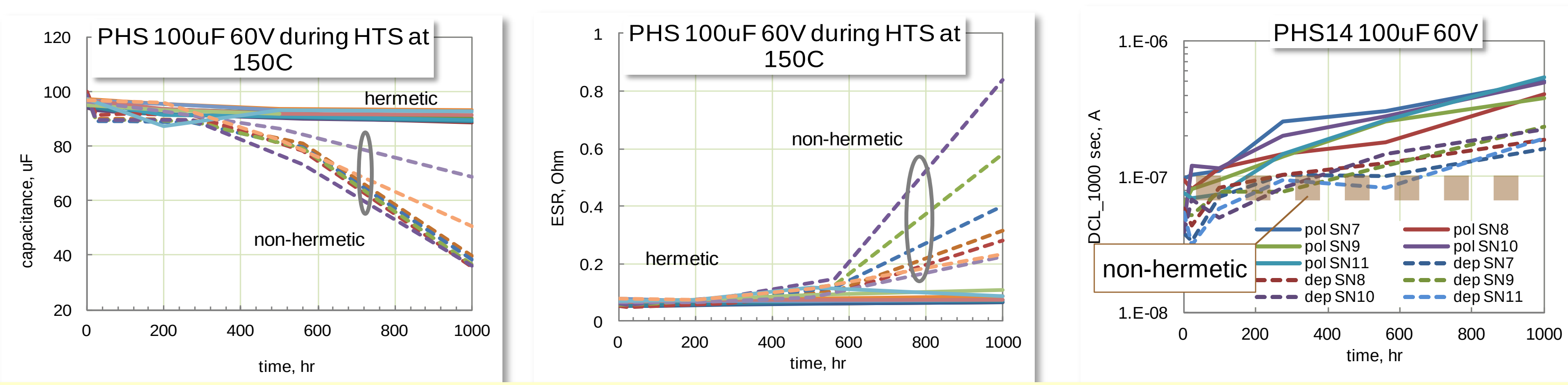


Polymer Tantalum Capacitors



- A report on evaluation of PHS capacitors manufactured per DLA LAM DWG#13030 (https://nepp.nasa.gov/):
  Literature review; analysis of requirements; characteristics, including thermal resistance; behavior of DCL under forward and reverse bias, recommendations.
- Specific feature: operation of polymer capacitors requires certain amount of moisture in the case. What happens if cases dry out?

Variations of capacitance, ESR, and DCL with time of HTS

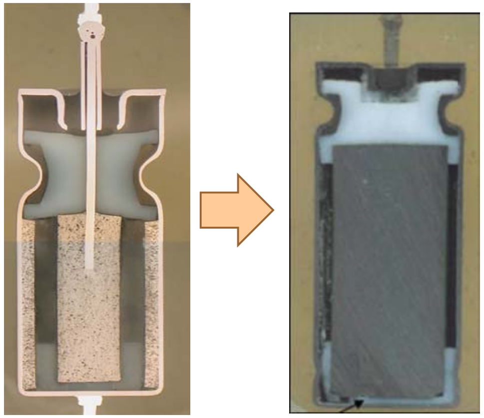


- ✓ PHS can survive 1000 hr storage at 150°C without degradation.
- ✓ Non-hermetic parts degraded due to a substantial decrease in capacitance and increase in ESR caused likely by increasing resistance of the polymer.

Recommendations for Use of PHS

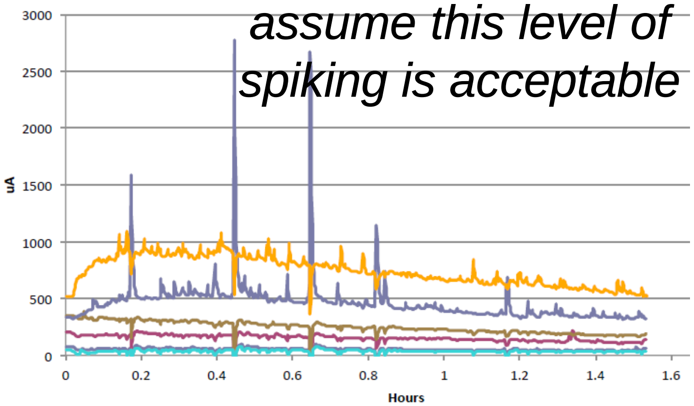
- PHS capacitors have lower weight and ESR compared to similar case size wet tantalum capacitors and their application in power lines can assure better filtering and lower ripple currents.
- Polymer capacitors would mostly benefit low-temperature applications (below 0°C) or systems where a cold start-up is required. However, additional application-specific testing are required if the parts are to be used at T < -55°C.
- Self-healing capability of PHS is much worse than wet capacitors and flaws in the dielectric that might be forgiven in wet capacitors might cause catastrophic failures in PHS. This requires a close attention to the results of S&Q, specifically, to measurements of leakage currents through the testing.

Random Vibration Testing



- Report is available at https://nepp.nasa.gov/
- Problems in assurance robustness of capacitors under RVT have a long history.
- Larger anode size increases the stress during RVT.
- Existing requirements and practice:
  - MIL-PRF-39006: 1.5hr in 3 directions; 30 min monitoring every 0.5 msec "*to determine intermittent open-circuiting or short-circuiting*".
  - Test techniques and failure criteria are not specified allowing different test labs to carry out testing differently, e.g limiting resistors from ohms to dozens of kohms, and failure criteria vary from 5% to 90% of VR.

Some test labs assume this level of spiking is acceptable



- ✓ Different set-ups have different sensitivity to short-circuiting.
- ✓ Different failure criteria cause inconsistency in test results.
- ✓ A single scintillation event is sufficient to cause lot failure.

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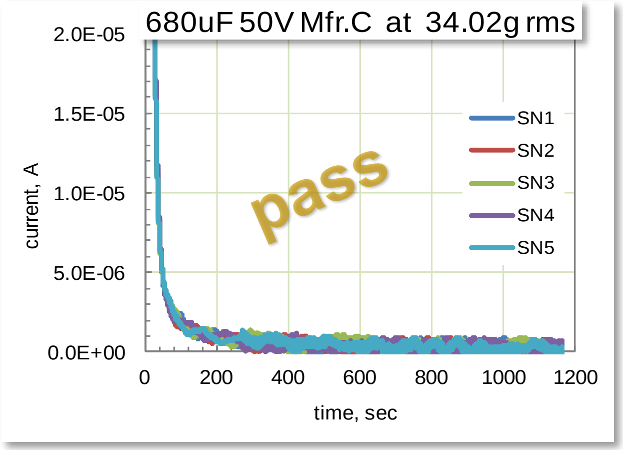
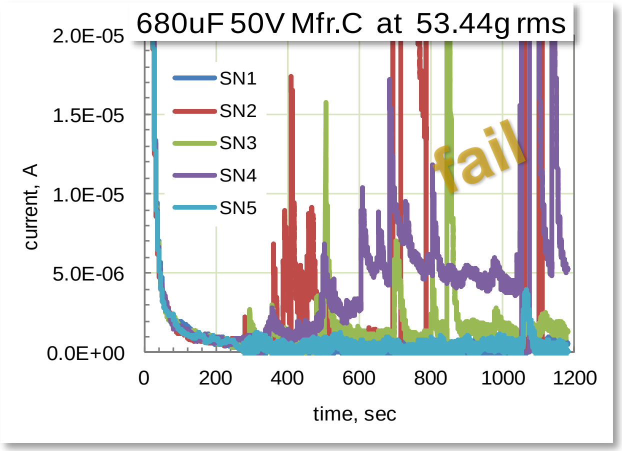
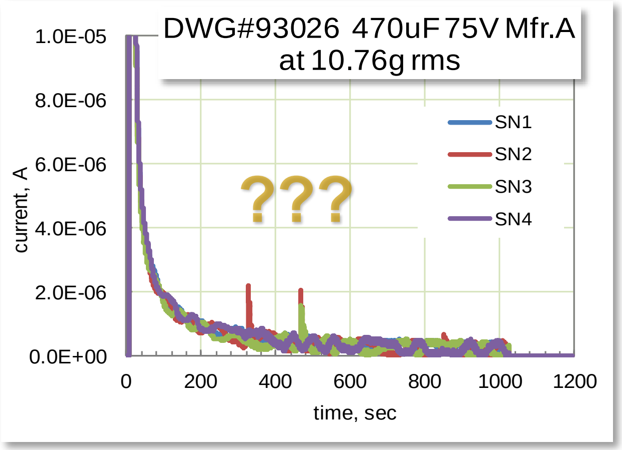
RVT: Step Stress Testing

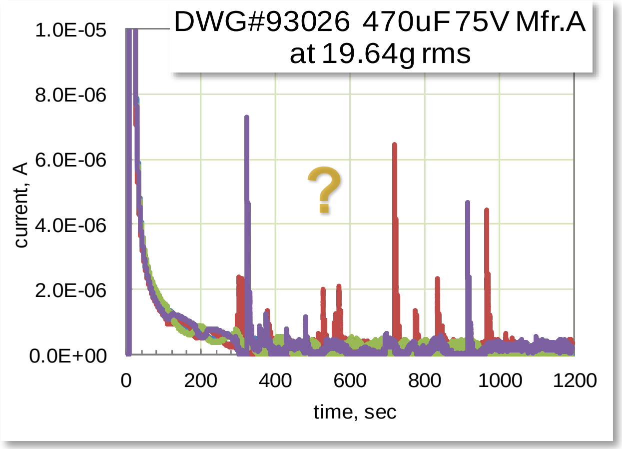
Example of a part passing RVT at 34 g rms and failing at 53.44 g rms





Did this part fail at 10.76 g rms, at 19.64 g rms?

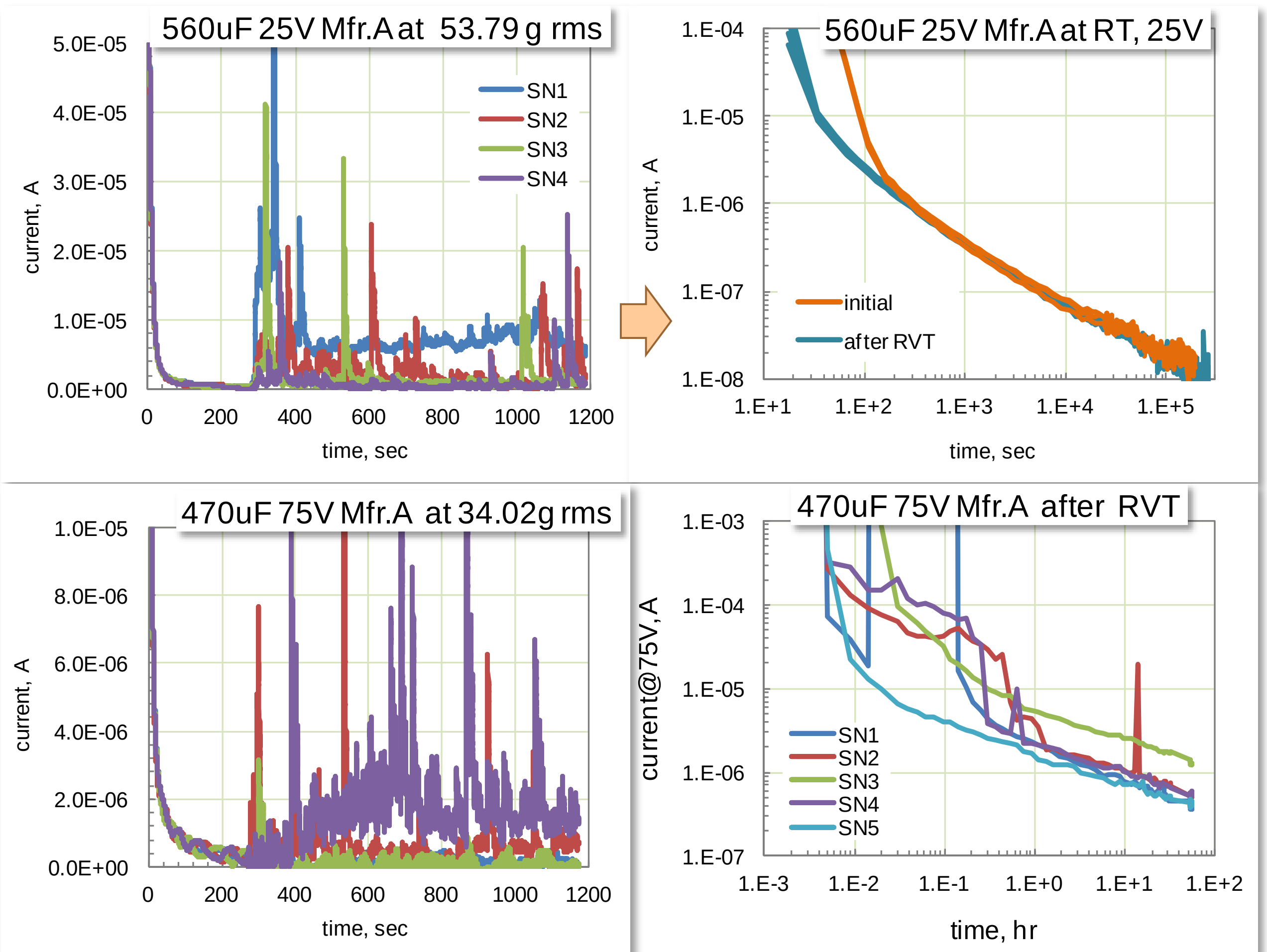




RVT: Post-testing Leakage Currents

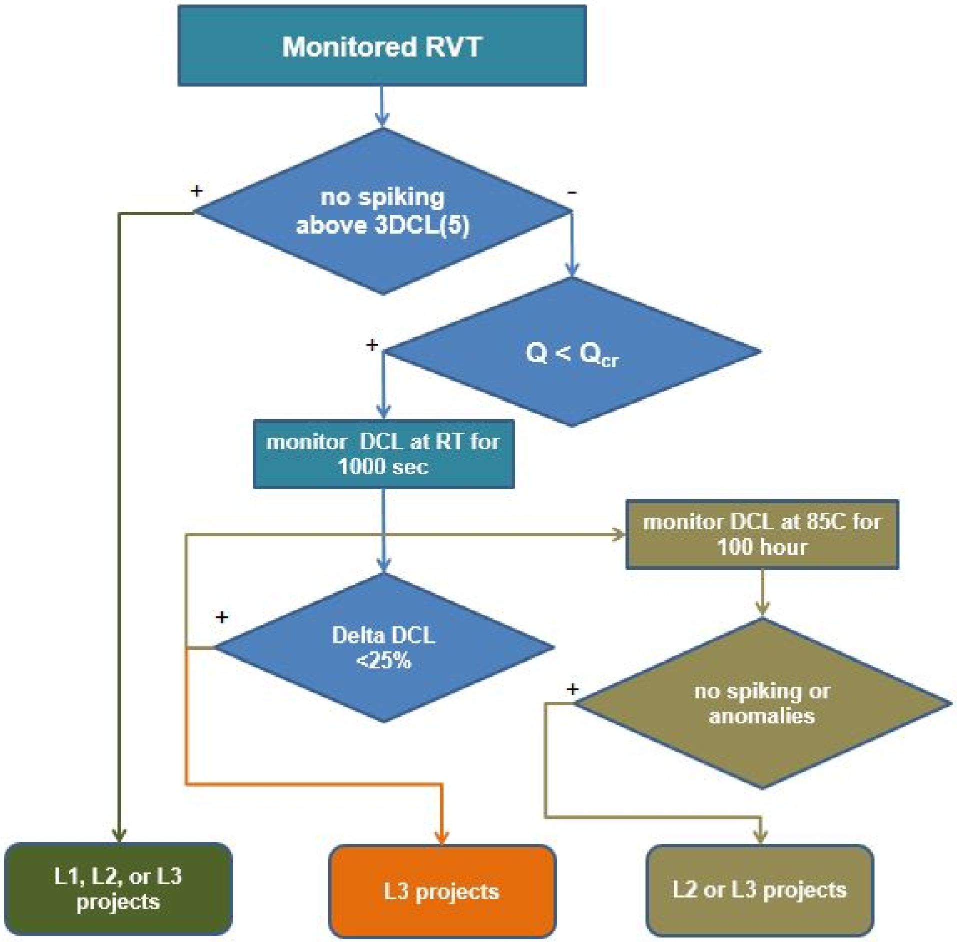
Leakage currents were monitored with time after RVT.

Currents during RVT *Currents after RVT*



- ✓ Spiking during RVT might not result in DCL failures after the testing.
- ✓ 560 µF 25 V capacitors passed HALT after RVT at 53.8 g rms.
- ✓ Parts with excessive currents are recovering with time under bias.

RVT: Recommendations



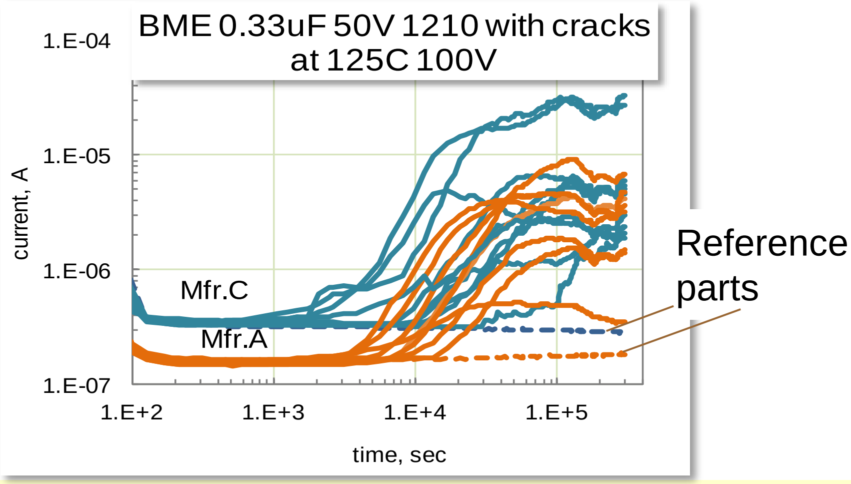
- ✓ Different tests for different risk levels.
- ✓ Each lot should be tested.
- ✓ Typical testing:
  - 19.6 g rms , 6 samples.
  - 15 min in each direction.
  - DCL is monitored (10k, 0.1sec sampling).
  - Criterion I: $I_{sp} > 3DCL(5) = 3\times I_{300}$
  - Criterion II: $Q > Q_{cr}$
  - Criterion III: $I_{300\_RVT} < 1.25\times I_{300\_init}$
- ✓ Lots older than 5 years should be retested.

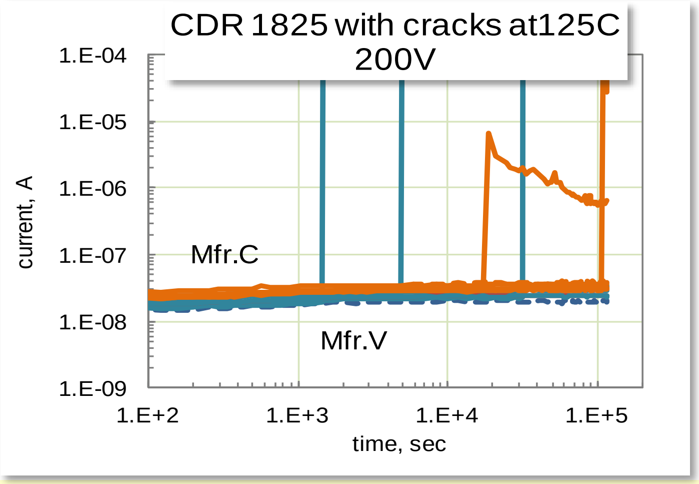
Future Work on Tantalum Capacitors

- MnO2 chip capacitors.
  - Rapid assessment of reliability acceleration factors.
  - Degradation during long-term operation under reverse bias.
- Advanced wet capacitors.
  - Analysis of DCL(T, V, t), breakdown processes, gas generation, and requirements for S&Q.
  - Effect of HT storage on performance and reliability.
- Polymer capacitors.
  - Evaluation of chip tantalum capacitors and requirements for S&Q.
  - Evaluation of new types of hermetically sealed capacitors.
- Solid electrolyte super-capacitors for space application.

Life Testing of MLCCs with Cracks

Typical variations of currents during HALT

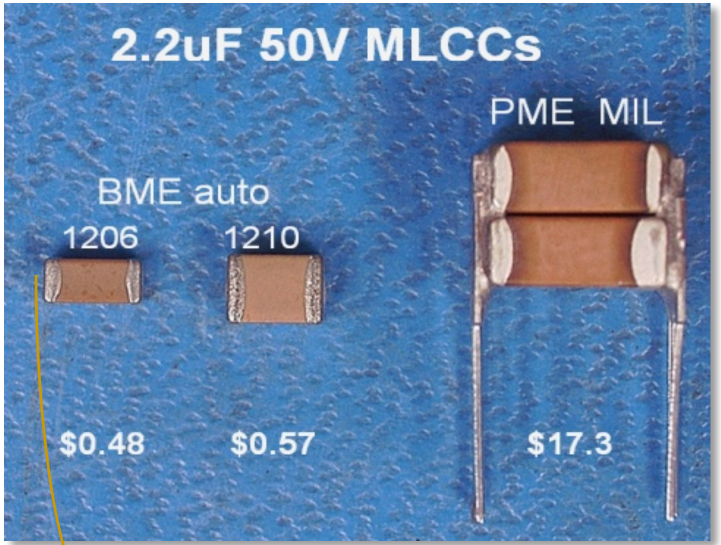




- ✓ Cracking does not affect IR at 125 °C but facilitates degradation of leakage currents.
- ✓ In the presence of cracks, currents in BMEs start increasing after a few hours of testing, but stabilize with time.
- ✓ Degradation in PMEs with cracks occurs at much higher levels of stress, and contrary to BMEs results in instantaneous short circuit failures (due to HT silver migration?).
- ✓ Contrary to humid environments, at high temperatures, BMEs with cracks degrade faster than PMEs (degradation vs. catastrophic failures).

Can we Use "AUTO" Capacitors?

- Benefits of using "auto" grade capacitors are obvious.
- Adaptation of "auto" components should start after ~5 years on the market.
- For MLCCs we are ~10 years late.
- Major QA problems:
  - Lead-free terminations (Sn whiskers).
  - "Insufficient screening" (no BI)
  - Lack of long-term reliability data.
- Issues to discuss:
  - Acceptable measures to mitigate whiskering.
  - Why do we need burning-in?
  - What long-term testing tells us?



0201, smartphones

Whiskering

- Can be mitigated by using Sn/Pb solder, conformal coating, etc.
- JAXA uses HSD to replace Sn on "auto" BMEs with Sn/Pb followed by additional screening.

Is Burning-In Necessary?

QA wisdom: *"Reliability should be designed into product and processes, but not screened out by testing".*

- ❑ In practice, we require that parts for space applications go through BI.
- ❑ The purpose of BI is to remove IM failures from the lot.

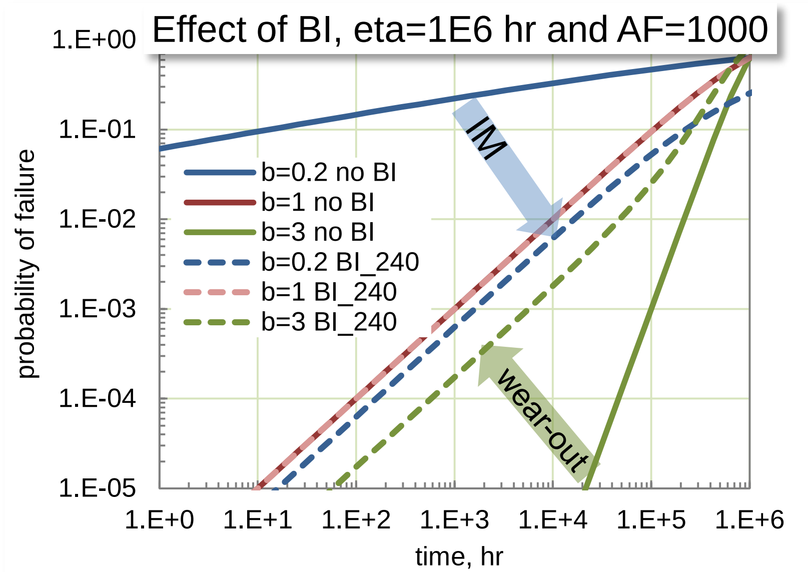
Weibull distribution determines type of failures

$$\lambda(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1}$$

β < 1 => IM failures
β = 1 => random failures
β > 1 => wear-out failures

Probability of failure after BI for t_{BI} hrs

$$F(t) = \frac{F(t + AF \times t_{BI}) - F(AF \times t_{BI})}{1 - F(AF \times t_{BI})} \qquad F(\tilde{t}) = 1 - \exp\left[-\left(\frac{\tilde{t}}{\eta}\right)^{\beta}\right]$$



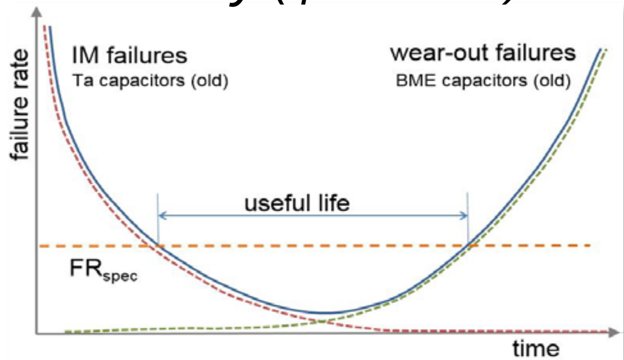
- ✓ BI is useless if lots do not have IM or their proportion is below a certain level.
- ✓ BI reduces useful life for lots susceptible to wear-out.
- ✓ Burning-In might be not necessary.

What Results of Life Testing Mean?

Life testing is typically a qualification (qualitative), not a reliability (quantitative) test.

- Still, FR can be estimated if:
  - There is no significant lot-to-lot variations.
    (Verification of consistency of quality is built into MIL system. There is a greater portion of "trust/relationship" in "auto" industry.)
  - Same mechanisms at life test and normal conditions.
    (not always so, e.g. moisture, cracking/soldering)
  - Failures are random ($\beta = 1$).
    (probably never happens; instead: $\lambda =$ const < FR_{spec}).
  - Accelerating factors are known.
    (Is not true in most cases.)

$$\lambda = \frac{\chi^2(\alpha, 2n+2)}{2} \times \frac{1}{AF} \times \frac{10^5}{N \times t}$$



FR(in %/1000hr at 60% conf) at 50ºC, 0.5VR based on life testing of 22 samples

	PME		BME	
	1000 hr	10,000 hr	1000 hr	10,000 hr
failures	0	1	0	1
PV const.	n_V= 3, E_a= 0.8eV		n_V= 4, E_a= 1.1eV	
AF	14,404		439,199	
FR	2.9E-04	6.4E-05	9.5E-06	2.1E-06

- ✓ Field failures are typically due to conditions that are not simulated by life testing.
- ✓ Without AF, comparison of life tests (PME vs. BME) is not correct.
- ✓ Emphasizing importance of 10 khr HALT can mislead manufacturers. The focus should be on consistency of quality.

Future Work on Ceramic Capacitors

- Cracking-related problems.
  - Develop mechanical tests (board flex and strength) and assess their effectiveness for quality assurance.
  - Analysis of cracking on degradation and failures at high temperatures.
  - Develop recommendations to mitigate risks of manual soldering/rework.
- Comparative analysis of performance and reliability of BME and PME capacitors.
  - Breakdown voltages, leakage currents and insulation resistance.
  - Analysis of failures in BME capacitors with defects.
  - Express testing to determine reliability acceleration factors for BME capacitors.
  - Guidelines for selecting “auto” MLCCs for different project levels.
- Specifics of QA and attachment for small-size MLCCs.
- Analysis of requirements for stacking capacitors.